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ABSTRACT

Based on the Cox-Merz rule and Eyring's expression for the nonlinear shear viscosity, a Wagner type constitutive relation with no adjustable parameters is proposed for pure shear viscoelasticity. The predictions for a number of non-steady shear flows are worked out analytically. It is shown that most features of shear viscoelasticity are reproduced by the model.

1. INTRODUCTION

After several years of research a number of useful constitutive relations are now available [1]. In order to reproduce experiment accurately these relations all contain a number of fitting parameters. In this paper the following question is asked: What is the simplest possible constitutive relation which still reproduces important features of viscoelasticity? To simplify the discussion only pure shear viscoelasticity is considered, and normal stresses are ignored all together. Starting from the Cox-Merz rule, a simple Wagner type constitutive relation with no adjustable parameters is arrived at. The nonlinear steady state shear viscosity is, by construction, close to that predicted by Eyring's phenomenological theory of liquid flow [2]. Various non-steady shear flows are then considered and worked out analytically. Because there are no fitting parameters in the proposed model, no detailed comparison to experiment is made. However, it is shown that the constitutive relation reproduces most qualitative features of shear viscoelasticity.

2. THE MODEL

The well-known Cox-Merz rule [3] states that

$$\eta(\dot{\gamma}) = |\eta_0(\omega)| \Big|_{\omega=\dot{\gamma}} \tag{1}$$

where $\eta(\dot{\gamma})$ is the nonlinear shear viscosity as function of shear rate and $\eta_0(\omega)$ is the frequency-dependent viscosity in the linear response regime. The Cox-Merz rule is obeyed surprisingly well for most polymeric liquids, while exceptions are sometimes observed for inhomogeneous systems. The quantity $\eta_0(\omega)$ is obtained [1] from the equation

$$\eta_0(\omega) = \int_0^\infty dt' \, G(t') \, e^{-i\omega t'} \tag{2}$$

where G(t') is the relaxation modulus. By definition, G(t') determines the stress τ in the linear limit from the shear rate history by means of

$$\tau(t) = \int_0^\infty dt' \, G(t') \, \dot{\gamma}(t-t'). \tag{3}$$

From Eqs. (1) and (2) one expects the Cox-Merz rule to be satisfied if

$$\eta(\dot{\gamma}) = \int_0^\infty dt' \, G(t') \, e^{-\dot{\gamma} t'} \qquad (\dot{\gamma} > 0). \tag{4}$$

A straightforward generalization of Eq. (3) to include Eq. (4) for the stationary case is the following constitutive relation

$$\tau(t) = \int_0^\infty dt'\, G(t')\,\dot\gamma(t-t')\exp\left\{-\int_{t-t'}^{t} |\dot\gamma(t'')|\,dt''\right\} \tag{5}$$

Equation (5) is similar to Wagner's constitutive relation [1,4]. The difference is that, in the "linear" part of the relation, γ in Wagner's model is here replaced by $\dot\gamma$. More importantly, the "damping function" is here $\exp\left\{-\int_{t-t'}^{t}|\dot\gamma|\right\}$ instead of Wagner's $\exp\left\{-\left|\int_{t-t'}^{t}\dot\gamma\right|\right\}$. The present choice of damping function is suggested because this damping function sums over all shear displacement taking place between time $t-t'$ and t.

Next, a specific form of $G(t')$ is chosen, namely $G(t') = E_1(t')$ where $E_1(t')$ is the exponential integral [5]

$$E_1(t') = \int_{t'}^{\infty} e^{-u}\,\frac{du}{u} \tag{6}$$

For convenience we here and henceforth work with dimensionless time, stress and viscosity, the latter quantity normalized so that $\eta_0(\omega=0)=1$. The final constitutive relation is

$$\tau(t) = \int_0^\infty dt'\, E_1(t')\,\dot\gamma(t-t')\exp\left\{-\int_{t-t'}^{t}|\dot\gamma(t'')|\,dt''\right\}. \tag{7}$$

The use of $E_1(t')$ as the relaxation modulus is motivated by the fact that this choice leads to a nonlinear viscosity which is close to that predicted by Eyring's phenomenological theory of liquid flow [2] which fits many experiments:

$$\eta(\dot{\gamma}) = \frac{\sinh^{-1}(\dot{\gamma})}{\dot{\gamma}} \tag{8}$$

To see this, note that the Laplace transform of E_1 is [5]

$$\tilde{E}_1(s) = \frac{\ln(1+s)}{s} \tag{9}$$

so the nonlinear viscosity is given by

$$\eta(\dot{\gamma}) = \frac{\ln(1+\dot{\gamma})}{\dot{\gamma}} \quad . \tag{10}$$

From the identity $\sinh^{-1}(x) = \ln(x+\sqrt{1+x^2})$ it follows that Eyring's nonlinear shear viscosity is close to that predicted in Eq. (10). This is illustrated in Fig. 1 which also shows that the Cox-Merz rule is obeyed by the constitutive relation, as expected. This observation is based on the fact that the frequency-dependent linear viscosity is given by

$$\eta_0(\omega) = \int_0^\infty dt' \, E_1(t') e^{-i\omega t'} = \frac{\ln(1+i\omega)}{i\omega} \tag{11}$$

which implies for the real part and for the (negative) imaginary part

$$\begin{aligned} \eta'(\omega) &= \mathrm{Arctan}(\omega)/\omega \\ \eta''(\omega) &= \ln\sqrt{1+\omega^2}/\omega \quad . \end{aligned} \tag{12}$$

We now proceed to calculate the time-dependent nonlinear response in various situations, following Chap. 3.4 in Ref. 1.

Consider first the stress growth upon inception of a steady shear flow, i. e. , the case when the shear rate is given by

$$\dot{\gamma}(t) = \begin{cases} 0 \quad , & t < 0 \\ \dot{\gamma}_0 \quad , & t > 0 \end{cases} \quad . \tag{13}$$

In this case Eq. (7) implies for the stress τ^+ :

$$\tau^+(t) = \dot{\gamma}_0 \int_0^t dt' \, E_1(t') e^{-\dot{\gamma}_0 t'} \tag{14}$$

or, for the quantity $\eta^+(t,\dot{\gamma}_0) = \tau^+(t)/\dot{\gamma}_0$,

$$\eta^+(t,\dot{\gamma}_0) = \int_0^t dt' \, E_1(t') e^{-\dot{\gamma}_0 t'} \quad . \tag{15}$$

After a partial integration Eq. (15) reduces to

$$\eta^+(t,\dot{\gamma}_0) = \left[E_1\left((1+\dot{\gamma}_0)t\right) - E_1(t)e^{-\dot{\gamma}_0 t} + \ln(1+\dot{\gamma}_0) \right] \Big/ \dot{\gamma}_0 \tag{16}$$

where use has been made of the fact that $E_1(t)$ varies as $\ln(t)$ for $t \to 0$. In Fig. 2 $\eta^+(t,\dot{\gamma}_0)$ is plotted in a logarithmic plot for different values of $\dot{\gamma}_0$. The figure shows that η^+ is always monotonously increasing. This is not quite like in experiment where there is usually a characteristic "overshoot" of η^+ as function of time before the steady state value is reached [1].

Consider now stress relaxation after cessation of a steady shear flow, i. e. , when

$$\dot{\gamma}(t) = \begin{cases} \dot{\gamma}_0 \quad , & t < 0 \\ 0 \quad , & t > 0 \end{cases} \tag{17}$$

Then Eq. (7) implies for the stress $\bar{\tau}$:

$$\bar{\tau}(t) = \dot{\gamma}_0 \int_t^{\infty} dt' \, E_1(t') \, e^{-\dot{\gamma}_0 (t'-t)} \quad . \tag{18}$$

Equations (10), (15) and (18) imply

$$\eta^+(t,\dot{\gamma}_0) + e^{-\dot{\gamma}_0 t} \eta^-(t,\dot{\gamma}_0) = \frac{\ln(1+\dot{\gamma}_0)}{\dot{\gamma}_0} \tag{19}$$

where $\eta^-(t,\dot{\gamma}_0) = \bar{\tau}(t)/\dot{\gamma}_0$. By means of Eq. (16) we thus find

$$\eta^-(t,\dot{\gamma}_0) = \left[E_1(t) - E_1\left((1+\dot{\gamma}_0)t\right) e^{\dot{\gamma}_0 t} \right] \Big/ \dot{\gamma}_0 \quad . \tag{20}$$

Fig. 3 shows η^- for various values of $\dot{\gamma}_0$. As in experiment one finds that $\eta^-(t,\dot{\gamma}_0)$ is a monotonously decreasing function of time for all $\dot{\gamma}_0$, and that η^- reaches zero faster the larger $\dot{\gamma}_0$ is.

We now turn to the calculation of stress relaxation after a sudden shearing displacement γ_0 . The shear rate is given by $\dot{\gamma}(t) = \gamma_0 \delta(t)$. Substituted into Eq. (7) this gives

$$\tau(t) = \left(1 - e^{-\gamma_0}\right) E_1(t) \tag{21}$$

which is easily shown by rewriting Eq. (7) as

$$\tau(t) = \int_0^{\infty} dt' \, E_1(t') \left[-\frac{d}{dt'} \right] e^{-\int_{t-t'}^{t} \dot{\gamma}} \tag{22}$$

valid whenever $\dot{\gamma} \geq 0$. For the relaxation modulus $G(t,\gamma_0) = \tau(t)/\gamma_0$, one thus finds

$$G(t,\gamma_0)=E_1(t)\left(1-e^{-\gamma_0}\right)/\gamma_0 . \tag{23}$$

For $\gamma_0 \to 0$ $G(t,\gamma_0)$ reduces to the linear response relaxation modulus $E_1(t)$. Equation (23) shows that $G(t,\gamma_0)$ factorizes into a function of time times a function of γ_0 , as expected for any Wagner type model [1,6].

Next we consider the calculation of the nonlinear creep compliance $J(t,\tau_0)$, defined as $\gamma(t)/\tau_0$ where $\gamma(t)$ is the total shear displacement in time t when a constant stress τ_0 is applied at $t=0$. The calculation of J from a constitutive relation is complicated by the fact that $\gamma(t)$ is only given indirectly. For the present constitutive relation, however, $\gamma(t)$ may be found analytically in the following way. First, Eq. (7) is rewritten for the case under consideration as

$$\tau_0 e^{\gamma(t)} = \int_0^t dt' \, E_1(t')\, \dot{\gamma}(t-t')\, e^{\gamma(t-t')} . \tag{24}$$

Equation (24) is linear in the variable $C(t)=\exp(\gamma(t))$:

$$\tau_0 \, C(t) = \int_0^t dt' \, E_1(t') \, \dot{C}(t-t') . \tag{25}$$

This equation is now Laplace transformed into

$$\tau_0 \, \tilde{C}(s) = \tilde{E}_1(s) \, \tilde{\dot{C}}(s) \tag{26}$$

or

$$\tilde{\dot{C}}(s) = \frac{\tau_0}{\ln(1+s) - \tau_0} \quad . \tag{27}$$

Here, use has been made of Eq. (9) and the identity $\tilde{\dot{C}}(s) = s\tilde{C}(s) - C(0) = s\tilde{C}(s) - 1$. $\tilde{C}(s)$ has a branch cut on the negative real axis from $s=-1$ to $s=-\infty$ and a pole at $s=\dot{\gamma}_0$, where

$$\dot{\gamma}_0 = e^{\tau_0} - 1 \tag{28}$$

is the steady state shear rate (Eq. (10)). The Laplace inversion of Eq. (27) is performed by deforming the integration contour to run from $-\infty$ slightly below the negative real axis, rounding the pole at $s=\dot{\gamma}_0$, and returning to $-\infty$ above the negative real axis. After standard manipulations one thus finds

$$\dot{C}(t) = \tau_0 (1+\dot{\gamma}_0) e^{\dot{\gamma}_0 t} + \tau_0 \int_1^\infty du\, e^{-ut} \frac{1}{[\ln(u-1) - \tau_0]^2 + \pi^2} \tag{29}$$

or finally, by integration with respect to time,

$$e^{J(t,\tau_0)\cdot\tau_0} = 1 + \tau_0 \frac{1+\dot{\gamma}_0}{\dot{\gamma}_0}\left(e^{\dot{\gamma}_0 t} - 1\right) + \tag{30}$$
$$+ \tau_0 \int_1^\infty du \frac{1-e^{-ut}}{u} \frac{1}{[\ln(u-1) - \tau_0]^2 + \pi^2} \quad .$$

In the linear limit Eq. (30) reduces to

$$J(t, \tau_0 \to 0) = t + \int_1^\infty du \frac{1-e^{-ut}}{u} \frac{1}{\ln^2(u-1) + \pi^2} \quad . \tag{31}$$

The creep compliance $J(t,\tau_0)$ of Eq. (30) is plotted in Fig. 4 in a log-log plot for different values of $\dot{\gamma}_0$.

As a final example of the use of Eq. (7) consider the constrained recoil after a steady shear flow is interrupted at $t=0$ by suddenly removing the shear stress. We wish to calculate the so-called recoverable shear γ_∞ . Writing

$$\dot{\gamma}(t) = \begin{cases} \dot{\gamma}_0 & , \ t<0 \\ -f(t) & , \ t>0 \end{cases} \quad , \tag{32}$$

Eq. (7) implies for $t>0$

$$0 = -\int_0^t dt' E_1(t') f(t-t') e^{-\int_{t-t'}^{t} f} + \int_t^\infty dt' E_1(t') \dot{\gamma}_0 e^{-\dot{\gamma}_0 (t'-t) - \int_0^t f} \tag{33}$$

or

$$\int_0^t dt' E_1(t') f(t-t') e^{\int_0^{t-t'} f} = \dot{\gamma}_0 e^{\dot{\gamma}_0 t} \int_t^\infty dt' E_1(t') e^{-\dot{\gamma}_0 t'} . \tag{34}$$

Defining $F(t)=\exp(\int_0^t f)$, Eq. (34) becomes

$$\int_0^t dt' E_1(t') \dot{F}(t-t') = \dot{\gamma}_0 e^{\dot{\gamma}_0 t} \int_t^\infty dt' E_1(t') e^{-\dot{\gamma}_0 t'} . \tag{35}$$

The Laplace transform of Eq. (35) is

$$\tilde{E}_1(s) \left(s \tilde{F}(s) - 1 \right) = \frac{\dot{\gamma}_0}{\dot{\gamma}_0 - s} \left(\tilde{E}_1(s) - \tilde{E}_1(\dot{\gamma}_0) \right) \tag{36}$$

or

$$\tilde{F}(s) = \frac{1}{s} \left[1 + \frac{\dot{\gamma}_0}{\dot{\gamma}_0 - s} \frac{\tilde{E}_1(s) - \tilde{E}_1(\dot{\gamma}_0)}{\tilde{E}_1(s)} \right] . \tag{37}$$

The recoverable shear is determined from $e^{\gamma_\infty} = \lim_{t\to\infty} F(t)$. This limit is given by the residue a the pole at s=0 of Eq. (37), and one finds $\gamma_\infty = \ln\left(2 - \tilde{E}_1(\dot{\gamma}_0)\right)$, or

$$\gamma_\infty = \ln\left(2 - \eta(\dot{\gamma}_0)\right) . \tag{38}$$

In the two limits one has

$$\gamma_\infty = \begin{cases} \frac{1}{2}\,\dot{\gamma}_0 & , \quad \dot{\gamma}_0 \ll 1 \\ \ln 2 & , \quad \dot{\gamma}_0 \gg 1 \end{cases} . \tag{39}$$

$\gamma_\infty(\dot{\gamma}_0)$ is monotonously increasing which is also the case in experiment. Also like in experiment, γ_∞ stabilizes on a recoverable shear of order one at high $\dot{\gamma}_0$.

3. DISCUSSION

The idea of this paper was to show that a simple constitutive relation with no adjustable parameters (except the overall scaling of time and viscosity) exists, which gives a qualitatively correct picture of shear viscoelasticity. Equation (7) was arrived at by requiring the Cox-Merz rule to be satisfied and that Eyring's nonlinear viscosity Eq. (8) is to be reproduced approximately. This ensures a nonlinear viscosity and a frequency-dependent linear viscosity which are both close to those observed in most experiments.

The choice of the linear relaxation modulus to be $E_1(t')$ may be justified instead from the box model, i. e. , the postulate of a uniform distribution of activation energies for microscopic motion. Consider the motion of a foreign microscopic particle in the liquid. Suppose the particle feels a spatially randomly varying potential energy, and that it moves by thermally activted hopping between the various potential energy minima. Then the linear mobility of the particle (the velocity divided by an external force acting on the particle), is given by

$$\mu(\omega) = \mu(0) \frac{i\omega}{\ln(1+i\omega)} \tag{40}$$

to a good approximation [6]. Assuming the Stokes law is valid for the particle, one has $\mu(\omega) \propto \eta^{-1}(\omega)$ which shows that the linear relaxation modulus of the liquid is $E_1(t')$ in this approximation.

Because the Cox-Merz rule is obeyed by the model it is not surprising that the Gleissele mirror relation [1] is also satisfied: The linear limit of η^+ from Eq. (16) is

$$\lim_{\dot{\gamma}_0 \to 0} \eta^+(t, \dot{\gamma}_0) = t E_1(t) - e^{-t} + 1 . \tag{41}$$

Gleissele's mirror relation states that $\eta(\dot{\gamma})$ is equal to this limit evaluated at $t = 1/\dot{\gamma}$, thus

$$\eta(\dot{\gamma}) = \begin{cases} 1 , & \dot{\gamma} \ll 1 \\ (1 - C + \ln \dot{\gamma})/\dot{\gamma} , & \dot{\gamma} \gg 1 \end{cases} \tag{42}$$

where C=0.577... is Euler's constant. A comparison of Eqs. (10) and (42) shows that the mirror relation is indeed satisfied to a good approximation.

The constitutive relation Eq. (7) reproduces most qualitative features of shear viscoelasticity. (An exception is the overshoot usually observed in η^+ as function of time, where the present model predicts η^+ to increase monotonously to the steady state value.) The fact that qualitative features of experiment are generally reproduced is not surprising, given the similarity between the present model and the Wagner model which is well-known to give a satisfactory description of experiment. The main difference between the present model and Wagner's model is that the damping function is here $\exp(-\int_{t-t'}^{t} |\dot{\gamma}|)$ whereas Wagner has $\exp(-|\int_{t-t'}^{t} \dot{\gamma}|)$. The appearance of $\int_{t-t'}^{t} |\dot{\gamma}|$ in the damping function is a simple way to incorporate irreversibility [7] into the model, i. e. , to reflect that segments are lost irreversibly during any deformation. A possible objection to this kind of damping term is that, for a periodic shear $\gamma = \gamma_0 \sin(\omega t)$, one might expect nonlinearity to set in at high frequencies even at very small amplitudes (because the damping apparently is a function of $\gamma_0 \omega$, and not of γ_0). This, however, is not correct: Suppose the worst possible case of the nonlinearity, i. e. , put the damping function equal to $\exp(-\omega\gamma_0 t')$ in Eq. (7). Then the response is

$$\tau(t) = \gamma_0 \omega \int_0^\infty dt' E_1(t') \cos(\omega(t-t')) e^{-\omega\gamma_0 t'}$$
$$= \gamma_0 \omega \left[\cos(\omega t) \operatorname{Re} g - \sin(\omega t) \operatorname{Im} g \right] \tag{43}$$

where

$$g = \int_0^\infty dt' E_1(t') e^{-(i\omega + \gamma_0 \omega) t'} = \frac{\ln(1+x)}{x}, \quad x = i\omega + \gamma_0 \omega . \tag{44}$$

At a fixed ω the onset of nonlinearity may be estimated from

$$\gamma_0 \omega \simeq \left| \frac{g(x)}{g'(x)} \right| \Bigg|_{x = i\omega} \tag{45}$$

which is the criterion for the first order term being equal to the zero'th order term in the Taylor expansion of g as function of γ_0 . Equation (45) leads to

$$\gamma_0 \omega \simeq \omega \left| \frac{\ln(1+i\omega)}{\frac{i\omega}{1+i\omega} - \ln(1+i\omega)} \right| \tag{46}$$

It is now easy to see that whenever $\omega \gtrsim 1$ the onset of nonlinearity takes place for γ_0 of order one. For $\omega \ll 1$, on the other hand, the onset of nonlinearity is at $\gamma_0 \simeq \omega^{-1}$ corresponding to a maximum shear rate of order one in the periodic variation.

REFERENCES

1. R B Bird, R C Armstrong, and O Hassager: "Dynamics of Polymeric Liquids", Vol. I and II, (Wiley, New York, 1987).
2. J F Kincaid, H Eyring, and A E Stearn, Chem Rev. **28**, 301-365 (1941).
3. W P Cox and E H Merz, J. Polym. Sci. **28**, 619-622 (1958).
4. M H Wagner, Rheol. Acta **18**, 33-50 (1979).
5. M Abramowitz and I A Stegun (Eds.): "Handbook of Matematical Functions" (Dover Publications, New York, 1972).
6. J C Dyre, J. Appl. Phys. **64**, 2456-2468 (1988).
7. M H Wagner and S E Stephenson, J. Rheol. **23**, 489-504 (1979).

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FIGURE CAPTIONS

Fig. 1: Log-log plot of various quantities characterizing the model. In this figure, as everywhere in the paper, dimensionless time, stress, and viscosity are used, the latter quantity normalized so that $\eta_0(\omega=0)=1$. The figure shows: (1) The predicted nonlinear viscosity as function of $\chi=\dot{\gamma}$ (•) (Eq. (10)), (2) Eyring's nonlinear viscosity as function of $\chi=\dot{\gamma}$ (Δ) (Eq. (8)), (3) $|\eta_0(\omega=\chi)|$ (∇) (Eq. (11)), and (4) the real (+) and the imaginary (X) part of $\eta_0(\omega=\chi)$. A comparison of the • and Δ points shows that Eyring's viscosity, which is known to give a good fit to many experiments, is reproduced reasonably well by the model. Comparing the • and the ∇ points shows that the Cox-Merz rule is obeyed, though not quite accurately in the transition region. The real and imaginary parts of $\eta_0(\omega)$ looks much like in experiment.

Fig. 2: Stress growth upon inception of a steady shear flow with shear rate $\dot{\gamma}_0$. The quantity $\eta^+(t,\dot{\gamma}_0)$ given by Eq. (16) is plotted as function of time for: (a) $\dot{\gamma}_0=0.1$ (reflecting the linear limit), (b) $\dot{\gamma}_0=3$, (c) $\dot{\gamma}_0=10$, and (d) $\dot{\gamma}_0=30$. Like in experiment, $\eta^+(t,\dot{\gamma}_0)$ follows the linear $\eta^+(t)$ for short times while it stabilizes for large t at the nonlinear viscosity, a stabilization which takes

place sooner the larger $\dot{\gamma}_0$ is. The overshoot of $\eta^+(t,\dot{\gamma}_0)$ often seen in experiment is not reproduced by the model.

Fig. 3: Stress growth after cessation of a steady shear flow with shear rate $\dot{\gamma}_0$. The figure shows the quantity $\eta^-(t,\dot{\gamma}_0)/\eta(\dot{\gamma}_0)$ as function of time, where η^- is given by Eq. (20), for: (a) $\dot{\gamma}_0 = 0.1$ (reflecting the linear limit), (b) $\dot{\gamma}_0 = 3$, and (c) $\dot{\gamma}_0 = 30$. As in experiment, $\eta^-(t,\dot{\gamma}_0)$ decreases to zero as $t \to \infty$ faster the larger $\dot{\gamma}_0$ is.

Fig. 4: Creep compliance $J = \gamma(t)/\tau_0$ where J is given by Eq. (30), plotted as function of time for: (a) $\dot{\gamma}_0 = 0.1$ (reflecting the linear limit), (b) $\dot{\gamma}_0 = 1$, (c) $\dot{\gamma}_0 = 10$, and (d) $\dot{\gamma}_0 = 100$, where $\dot{\gamma}_0$ is related to τ_0 by Eq. (28).

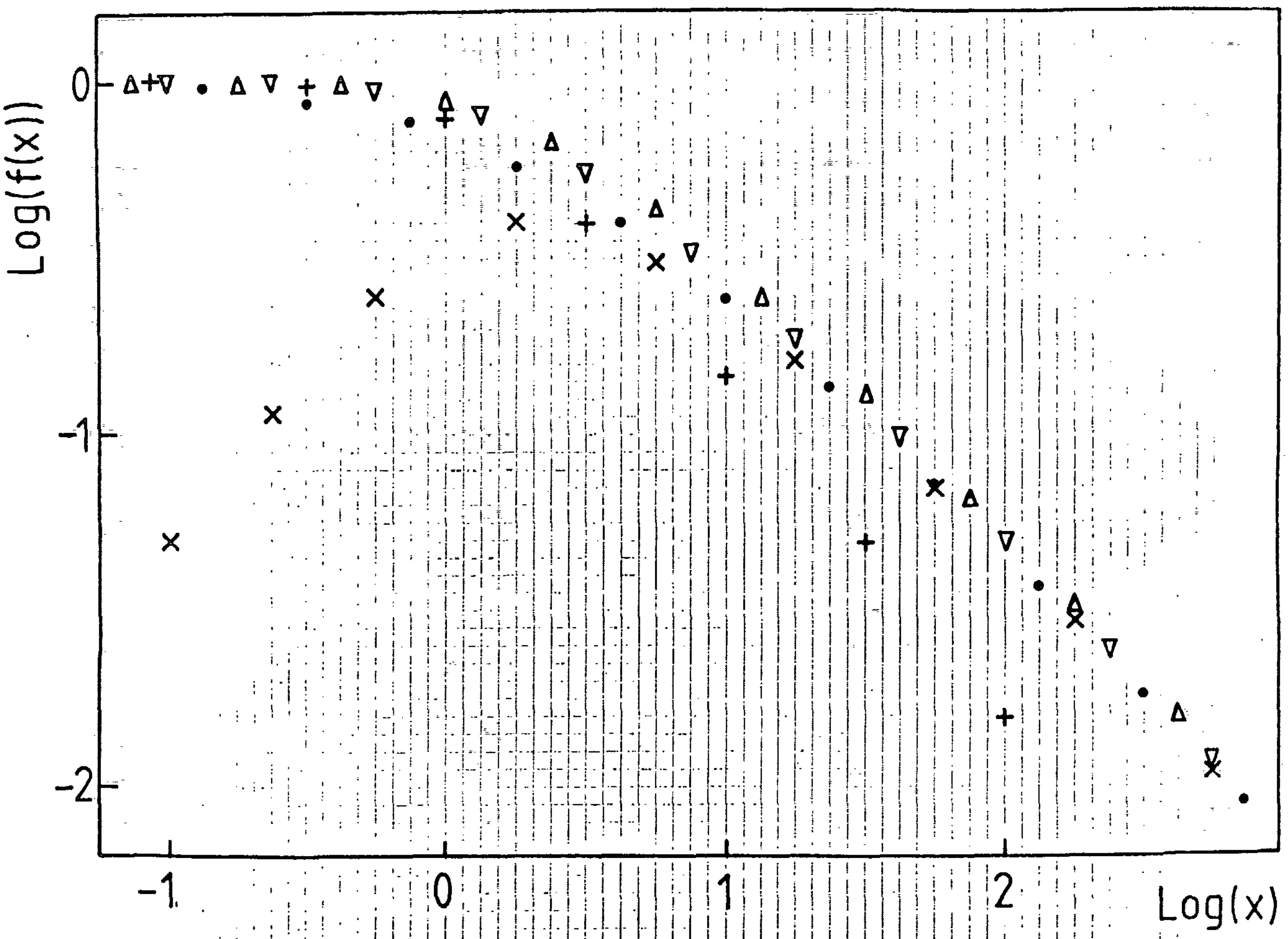

Fig. 1

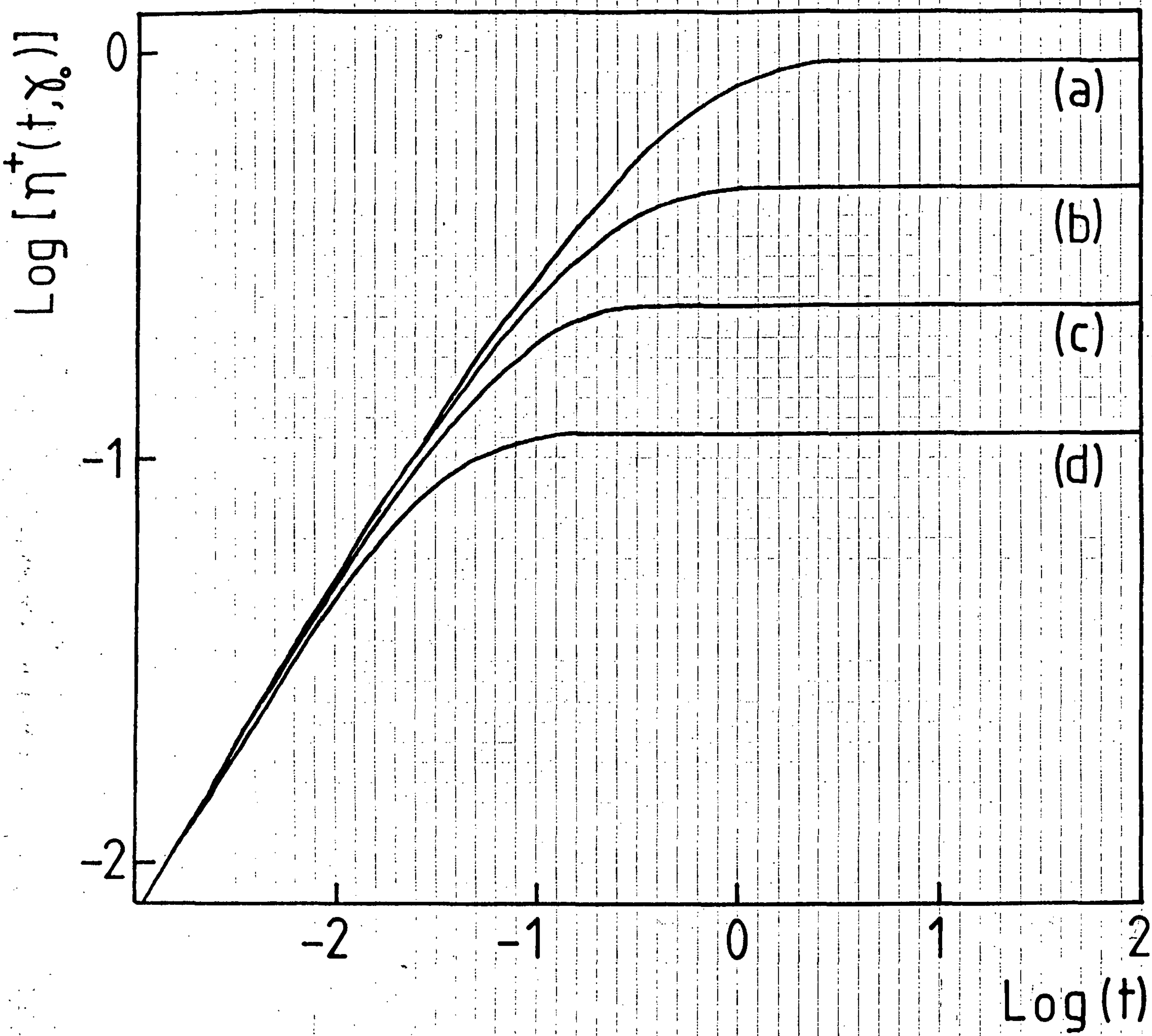

Fig. 2

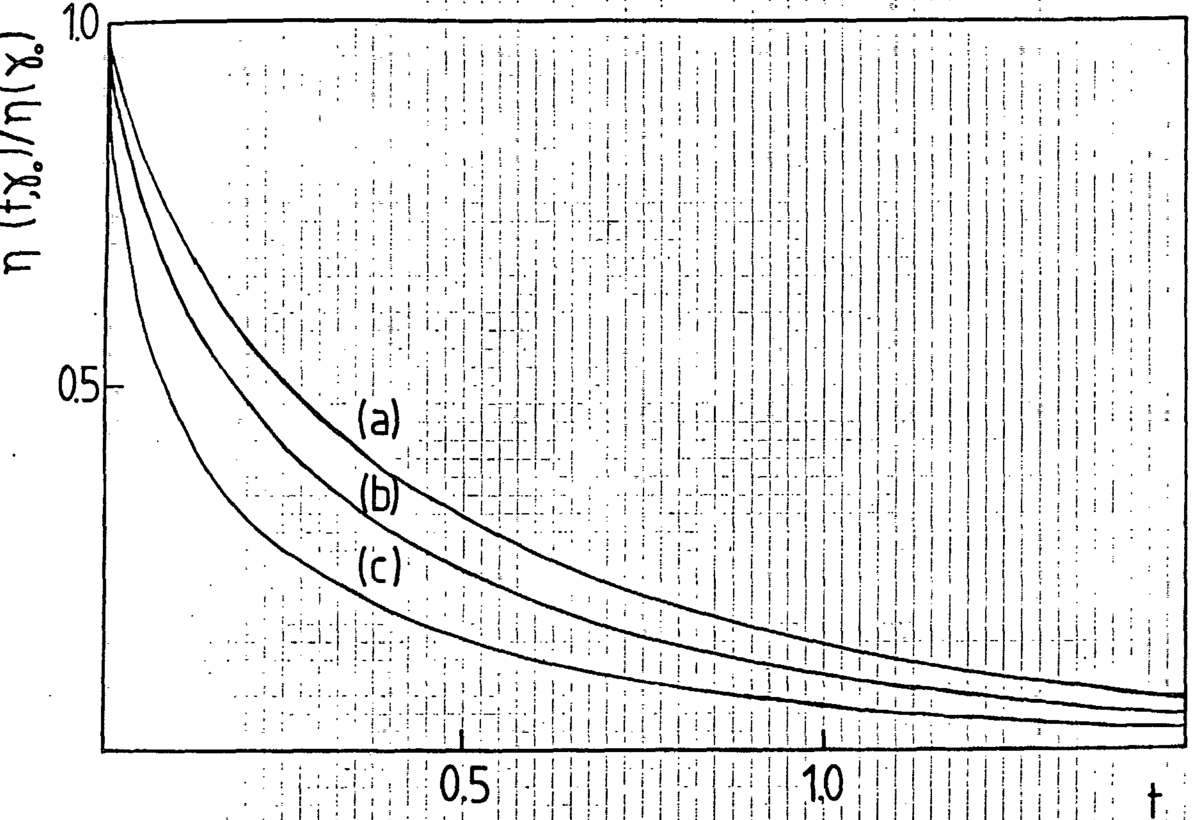

Fig. 3

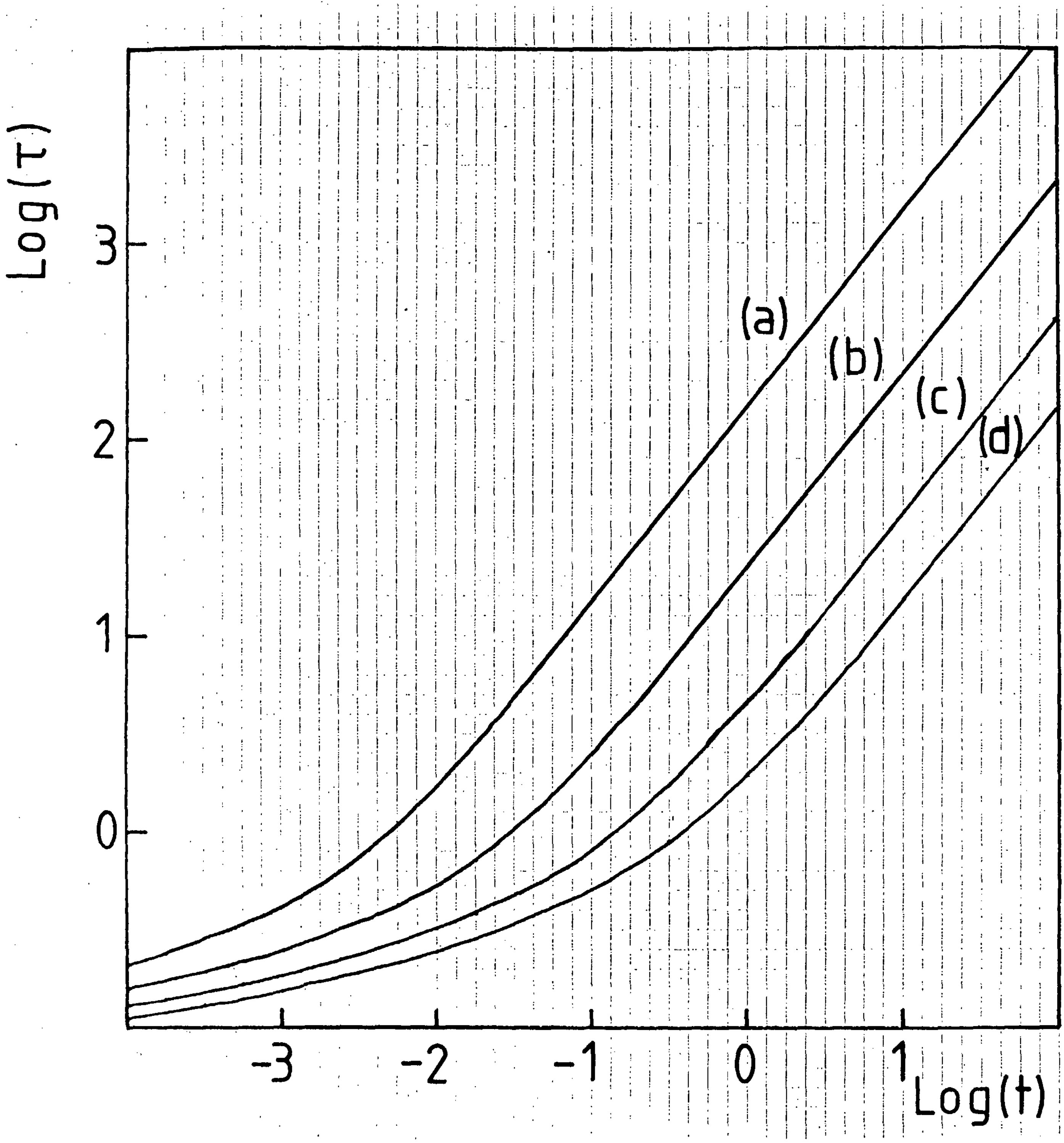

Fig. 4

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18/79 "MATHEMATICS AND THE REAL WORLD", Proceedings af an International Workshop, Roskilde University Centre, Denmark, 1978. Preprint. Af: Bernhelm Booss og Mogens Niss (eds.)

19/79 "GEOMETRI, SKOLE OG VIRKELIGHED". Projektrapport af: Tom J. Andersen, Tommy R. Andersen og Per H.H. Larsen. Vejleder: Mogens Niss.

20/79 "STATISTISKE MODELLER TIL BESTEMMELSE AF SIKRE DOSER FOR CARCINOGENE STOFFER". Projektrapport af: Michael Olsen og Jørn Jensen. Vejleder: Jørgen Larsen

21/79 "KONTROL I GYMNASIET-FORMÅL OG KONSEKVENSER". Projektrapport af: Crilles Bacher, Per S.Jensen, Preben Jensen og Torben Nysteen.

22/79 "SEMIOTIK OG SYSTEMEGENSKABER (1)". 1-port lineært response og støj i fysikken. Af: Peder Voetmann Christiansen.

23/79 "ON THE HISTORY AF EARLY WAVE MECHANICS - with special emphasis on the role af realitivity". Af: Helge Kragh.

24/80 a+b "MATEMATIKOPFATTELSER HOS 2.G'ERE". 1. En analyse. 2. Interviewmateriale. Projektrapport af: Jan Christensen og Knud Lindhardt Rasmussen. Vejleder: Mogens Niss.

25/80 "EKSAMENSOPGAVER", Dybdemodulet/fysik 1974-79.

26/80 "OM MATEMATISKE MODELLER". En projektrapport og to artikler. Af: Jens Højgaard Jensen m.fl.

27/80 "METHODOLOGY AND PHILOSOPHY AF SCIENCE IN PAUL DIRAC's PHYSICS". Af: Helge Kragh.

28/80 "DIELEKTRISK RELAXATION - et forslag til en ny model bygget på væskernes viscoelastiske egenskaber". Projektrapport af: Gert Kreinøe. Vejleder: Niels Boye Olsen.

29/80 "ODIN - undervisningsmateriale til et kursus i differentialligningsmodeller". Projektrapport af: Tommy R. Andersen, Per H.H. Larsen og Peter H. Lassen. Vejleder: Mogens Brun Heefelt.

30/80 "FUSIONSENERGIEN - - - ATOMSAMFUNDETS ENDESTATION". Af: Oluf Danielsen. Nr. 30 er udgået.

31/80 "VIDENSKABSTEORETISKE PROBLEMER VED UNDERVISNINGSSYSTEMER BASERET PÅ MÆNGDELÆRE". Projektrapport af: Troels Lange og Jørgen Karrebæk. Vejleder: Stig Andur Pedersen. Nr. 31 er p.t. udgået.

32/80 "POLYMERE STOFFERS VISCOELASTISKE EGENSKABER - BELYST VED HJÆLP AF MEKANISKE IMPEDANSMÅLINGER MÖSSBAUEREFFEKTMÅLINGER". Projektrapport af: Crilles Bacher og Preben Jensen. Vejledere: Niels Boye Olsen og Peder Voetmann Christiansen.

33/80 "KONSTITUERING AF FAG INDEN FOR TEKNISK - NATURVIDENSKABELIGE UDDANNELSER. I-II". Af: Arne Jakobsen.

34/80 "ENVIRONMENTAL IMPACT AF WIND ENERGY UTILIZATION". ENERGY SERIES NO. I. Af: Bent Sørensen Nr. 34 er udgået.

35/80 "HISTORISKE STUDIER I DEN NYERE ATOMFYSIKS UDVIKLING".
Af: Helge Kragh.

36/80 "HVAD ER MENINGEN MED MATEMATIKUNDERVISNINGEN?".
Fire artikler.
Af: Mogens Niss.

37/80 "RENEWABLE ENERGY AND ENERGY STORAGE".
ENERGY SERIES NO. 2.
Af: Bent Sørensen.

38/81 "TIL EN HISTORIETEORI OM NATURERKENDELSE, TEKNOLOGI OG SAMFUND".
Projektrapport af: Erik Gade, Hans Hedal, Henrik Lau og Finn Physant.
Vejledere: Stig Andur Pedersen, Helge Kragh og Ib Thiersen.
Nr. 38 er p.t. udgået.

39/81 "TIL KRITIKKEN AF VÆKSTØKONOMIEN".
Af: Jens Højgaard Jensen.

40/81 "TELEKOMMUNIKATION I DANMARK - oplæg til en teknologivurdering".
Projektrapport af: Arne Jørgensen, Bruno Petersen og Jan Vedde.
Vejleder: Per Nørgaard.

41/81 "PLANNING AND POLICY CONSIDERATIONS RELATED TO THE INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO ENERGY SUPPLY SYSTEMS".
ENERGY SERIES NO. 3.
Af: Bent Sørensen.

42/81 "VIDENSKAB TEORI SAMFUND - En introduktion til materialistiske videnskabsopfattelser".
Af: Helge Kragh og Stig Andur Pedersen.

43/81 1."COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS".
2."ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION".
ENERGY SERIES NO. 4.
Af: Bent Sørensen.

44/81 "HISTORISKE UNDERSØGELSER AF DE EKSPERIMENTELLE FORUDSÆTNINGER FOR RUTHERFORDS ATOMMODEL".
Projektrapport af: Niels Thor Nielsen.
Vejleder: Bent C. Jørgensen.

45/82 Er aldrig udkommet.

46/82 "EKSEMPLARISK UNDERVISNING OG FYSISK ERKENDESE-
1+11 ILLUSTRERET VED TO EKSEMPLER".
Projektrapport af: Torben O.Olsen, Lasse Rasmussen og Niels Dreyer Sørensen.
Vejleder: Bent C. Jørgensen.

47/82 "BARSEBÄCK OG DET VÆRST OFFICIELT-TÆNKELIGE UHELD".
ENERGY SERIES NO. 5.
Af: Bent Sørensen.

48/82 "EN UNDERSØGELSE AF MATEMATIKUNDERVISNINGEN PÅ ADGANGSKURSUS TIL KØBENHAVNS TEKNIKUM".
Projektrapport af: Lis Eilertzen, Jørgen Karrebæk, Troels Lange, Preben Nørregaard, Lissi Pedesen, Laust Rishøj, Lill Røn og Isac Showiki.
Vejleder: Mogens Niss.

49/82 "ANALYSE AF MULTISPEKTRALE SATELLITBILLEDER".
Projektrapport af: Preben Nørregaard.
Vejledere: Jørgen Larsen og Rasmus Ole Rasmussen.

50/82 "HERSLEV - MULIGHEDER FOR VEDVARENDE ENERGI I EN LANDSBY".
ENERGY SERIES NO. 6.
Rapport af: Bent Christensen, Bent Hove Jensen, Dennis B. Møller, Bjarne Laursen, Bjarne Lillethorup og Jacob Mørch Pedersen.
Vejleder: Bent Sørensen.

51/82 "HVAD KAN DER GØRES FOR AT AFHJÆLPE PIGERS BLOKERING OVERFOR MATEMATIK ?"
Projektrapport af: Lis Eilertzen, Lissi Pedersen, Lill Røn og Susanne Stender.

52/82 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS".
Af: Bernhelm Booss og Krzysztof Wojciechowski.

53/82 "THE CONSTITUTION OF SUBJECTS IN ENGINEERING EDUCATION".
Af: Arne Jacobsen og Stig Andur Pedersen.

54/82 "FUTURES RESEARCH" - A Philosophical Analysis of Its Subject-Matter and Methods.
Af: Stig Andur Pedersen og Johannes Witt-Hansen.

55/82 "MATEMATISKE MODELLER" - Litteratur på Roskilde Universitetsbibliotek.
En biografi.
Af: Else Høyrup.

Vedr. tekst nr. 55/82 se også tekst nr. 62/83.

56/82 "EN - TO - MANGE" -
En undersøgelse af matematisk økologi.
Projektrapport af: Troels Lange.
Vejleder: Anders Madsen.

57/83 "ASPECT EKSPERIMENTET"-
Skjulte variable i kvantemekanikken?
Projektrapport af: Tom Juul Andersen.
Vejleder: Peder Voetmann Christiansen.
Nr. 57 er udgået.

58/83 "MATEMATISKE VANDRINGER" - Modelbetragtninger over spredning af dyr mellem småbiotoper i agerlandet.
Projektrapport af: Per Hammershøj Jensen og Lene Vagn Rasmussen.
Vejleder: Jørgen Larsen.

59/83 "THE METHODOLOGY OF ENERGY PLANNING".
ENERGY SERIES NO. 7.
Af: Bent Sørensen.

60/83 "MATEMATISK MODEKSPERTISE"- et eksempel.
Projektrapport af: Erik O. Gade, Jørgen Karrebæk og Preben Nørregaard.
Vejleder: Anders Madsen.

61/83 "FYSIKS IDEOLOGISKE FUNKTION, SOM ET EKSEMPEL PÅ EN NATURVIDENSKAB - HISTORISK SET".
Projektrapport af: Annette Post Nielsen.
Vejledere: Jens Høyrup, Jens Højgaard Jensen og Jørgen Vogelius.

62/83 "MATEMATISKE MODELLER" - Litteratur på Roskilde Universitetsbibliotek.
En biografi 2. rev. udgave.
Af: Else Høyrup.

63/83 "GREATING ENERGY FUTURES:A SHORT GUIDE TO ENERGY PLANNING".
ENERGY SERIES No. 8.
Af: David Crossley og Bent Sørensen.

64/83 "VON MATEMATIK UND KRIEG".
Af: Berhelm Booss og Jens Høyrup.

65/83 "ANVENDT MATEMATIK - TEORI ELLER PRAKSIS".
Projektrapport af: Per Hedegård Andersen, Kirsten Habekost, Carsten Holst-Jensen, Annelise von Moos, Else Marie Pedersen og Erling Møller Pedersen.
Vejledere: Bernhelm Booss og Klaus Grünbaum.

66/83 "MATEMATISKE MODELLER FOR PERIODISK SELEKTION I ESCHERICHIA COLI".
Projektrapport af: Hanne Lisbet Andersen, Ole Richard Jensen og Klavs Frisdahl.
Vejledere: Jørgen Larsen og Anders Hede Madsen.

67/83 "ELEPSOIDE METODEN - EN NY METODE TIL LINEÆR PROGRAMMERING?"
Projektrapport af: Lone Biilmann og Lars Boye.
Vejleder: Mogens Brun Heefelt.

68/83 "STOKASTISKE MODELLER I POPULATIONSGENETIK"
- til kritikken af teoriladede modeller.
Projektrapport af: Lise Odgård Gade, Susanne Hansen, Michael Hviid og Frank Mølgård Olsen.
Vejleder: Jørgen Larsen.

69/83 "ELEVFORUDSÆTNINGER I FYSIK"
- en test i 1.g med kommentarer.
Af: Albert C. Paulsen.

70/83 "INDLÆRINGS - OG FORMIDLINGSPROBLEMER I MATEMATIK PÅ VOKSENUNDERVISNINGSNIVEAU".
Projektrapport af: Hanne Lisbet Andersen, Torben J. Andreasen, Svend Åge Houmann, Helle Glerup Jensen, Keld Fl. Nielsen, Lene Vagn Rasmussen.
Vejleder: Klaus Grünbaum og Anders Hede Madsen.

71/83 "PIGER OG FYSIK"
- et problem og en udfordring for skolen?
Af: Karin Beyer, Sussanne Blegaa, Birthe Olsen, Jette Reich og Mette Vedelsby.

72/83 "VERDEN IFØLGE PEIRCE" - to metafysiske essays, om og af C.S Peirce.
Af: Peder Voetmann Christiansen.

73/83 ""EN ENERGIANALYSE AF LANDBRUG"
- økologisk contra traditionelt.
ENERGY SERIES NO. 9
Specialeopgave i fysik af: Bent Hove Jensen.
Vejleder: Bent Sørensen.

74/84 "MINIATURISERING AF MIKROELEKTRONIK" - om videnskabeliggjort teknologi og nytten af at lære fysik.
Projektrapport af: Bodil Harder og Linda Szkotak Jensen.
Vejledere: Jens Højgaard Jensen og Bent C. Jørgensen.

75/84 "MATEMATIKUNDERVISNINGEN I FREMTIDENS GYMNASIUM"
- Case: Lineær programmering.
Projektrapport af: Morten Blomhøj, Klavs Frisdahl og Frank Mølgaard Olsen.
Vejledere: Mogens Brun Heefelt og Jens Bjørneboe.

76/84 "KERNEKRAFT I DANMARK?" - Et høringssvar indkaldt af miljøministeriet, med kritik af miljøstyrelsens rapporter af 15. marts 1984.
ENERGY SERIES No. lo
Af: Niels Boye Olsen og Bent Sørensen.

77/84 "POLITISKE INDEKS - FUP ELLER FAKTA?"
Opinionsundersøgelser belyst ved statistiske modeller.
Projektrapport af: Svend Åge Houmann, Keld Nielsen og Susanne Stender.
Vejledere: Jørgen Larsen og Jens Bjørneboe.

78/84 "JÆVNSTRØMSLEDNINGSEVNE OG GITTERSTRUKTUT I AMORFT GERMANIUM".
Specialrapport af: Hans Hedal, Frank C. Ludvigsen og Finn C. Physant.
Vejleder: Niels Boye Olsen.

79/84 "MATEMATIK OG ALMENDANNELSE".
Projektrapport af: Henrik Coster, Mikael Wennerberg Johansen, Povl Kattler, Birgitte Lydholm og Morten Overgaard Nielsen.
Vejleder: Bernhelm Booss.

80/84 "KURSUSMATERIALE TIL MATEMATIK B".
Af: Mogens Brun Heefelt.

81/84 "FREKVENSAFHÆNGIG LEDNINGSEVNE I AMORFT GERMANIUM".
Specialerapport af: Jørgen Wind Petersen og Jan Christensen.
Vejleder: Niels Boye Olsen.

82/84 "MATEMATIK - OG FYSIKUNDERVISNINGEN I DET AUTOMATISEREDE SAMFUND".
Rapport fra et seminar afholdt i Hvidovre 25-27 april 1983.
Red.: Jens Højgaard Jensen, Bent C. Jørgensen og Mogens Niss.

83/84 "ON THE QUANTIFICATION OF SECURITY":
PEACE RESEARCH SERIES NO. 1
Af: Bent Sørensen
nr. 83 er p.t. udgået

84/84 "NOGLE ARTIKLER OM MATEMATIK, FYSIK OG ALMENDANNELSE".
Af: Jens Højgaard Jensen, Mogens Niss m. fl.

85/84 "CENTRIFUGALREGULATORER OG MATEMATIK".
Specialerapport af: Per Hedegård Andersen, Carsten Holst-Jensen, Else Marie Pedersen og Erling Møller Pedersen.
Vejleder: Stig Andur Pedersen.

86/84 "SECURITY IMPLICATIONS OF ALTERNATIVE DEFENSE OPTIONS FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 2
Af: Bent Sørensen.

87/84 "A SIMPLE MODEL OF AC HOPPING CONDUCTIVITY IN DISORDERED SOLIDS".
Af: Jeppe C. Dyre.

88/84 "RISE, FALL AND RESURRECTION OF INFINITESIMALS".
Af: Detlef Laugwitz.

89/84 "FJERNVARMEOPTIMERING".
Af: Bjarne Lillethorup og Jacob Mørch Pedersen.

90/84 "ENERGI I 1.G - EN TEORI FOR TILRETTELÆGGELSE".
Af: Albert Chr. Paulsen.

91/85 "KVANTETEORI FOR GYMNASIET".
1. Lærervejledning
Projektrapport af: Biger Lundgren, Henning Sten Hansen og John Johansson.
Vejleder: Torsten Meyer.

92/85 "KVANTETEORI FOR GYMNASIET".
2. Materiale
Projektrapport af: Biger Lundgren, Henning Sten Hansen og John Johansson.
Vejleder: Torsten Meyer.

93/85 "THE SEMIOTICS OF QUANTUM - NON - LOCALITY".
Af: Peder Voetmann Christiansen.

94/85 "TREENIGHEDEN BOURBAKI - generalen, matematikeren og ånden".
Projektrapport af: Morten Blomhøj, Klavs Frisdahl og Frank M. Olsen.
Vejleder: Mogens Niss.

95/85 "AN ALTERNATIV DEFENSE PLAN FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 3
Af: Bent Sørensen

96/85 "ASPEKTER VED KRAFTVARMEFORSYNING".
Af: Bjarne Lilletorup.
Vejleder: Bent Sørensen.

97/85 "ON THE PHYSICS OF A.C. HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.

98/85 "VALGMULIGHEDER I INFORMATIONSALDEREN".
Af: Bent Sørensen.

99/85 "Der er langt fra Q til R".
Projektrapport af: Niels Jørgensen og Mikael Klintorp.
Vejleder: Stig Andur Pedersen.

100/85 "TALSYSTEMETS OPBYGNING".
Af: Mogens Niss.

101/85 "EXTENDED MOMENTUM THEORY FOR WINDMILLS IN PERTURBATIVE FORM".
Af: Ganesh Sengupta.

102/85 OPSTILLING OG ANALYSE AF MATEMATISKE MODELLER, BELYST VED MODELLER OVER KØERS FODEROPTAGELSE OG - OMSÆTNING".
Projektrapport af: Lis Eilertzen, Kirsten Habekost, Lill Røn og Susanne Stender.
Vejleder: Klaus Grünbaum.

103/85 "ØDSLE KOLDKRIGERE OG VIDENSKABENS LYSE IDEER".
Projektrapport af: Niels Ole Dam og Kurt Jensen.
Vejleder: Bent Sørensen.

104/85 "ANALOGREGNEMASKINEN OG LORENZLIGNINGER".
Af: Jens Jæger.

105/85 "THE FREQUENCY DEPENDENCE OF THE SPECIFIC HEAT AF THE GLASS REANSITION".
Af: Tage Christensen.

"A SIMPLE MODEL AF AC HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.
Contributions to the Third International Conference on the Structure of Non - Crystalline Materials held in Grenoble July 1985.

106/85 "QUANTUM THEORY OF EXTENDED PARTICLES".
Af: Bent Sørensen.

107/85 "EN MYG GØR INGEN EPIDEMI",
- flodblindhed som eksempel på matematisk modellering af et epidemiologisk problem.
Projektrapport af: Per Hedegård Andersen, Lars Boye, CarstenHolst Jensen, Else Marie Pedersen og Erling Møller Pedersen.
Vejleder: Jesper Larsen.

108/85 "APPLICATIONS AND MODELLING IN THE MATEMATICS CURRICULUM" - state and trends -
Af: Mogens Niss.

109/85 "COX I STUDIETIDEN" - Cox's regressionsmodel anvendt på studenteroplysninger fra RUC.
Projektrapport af: Mikael Wennerberg Johansen, Poul Katler og Torben J. Andreasen.
Vejleder: Jørgen Larsen.

110/85 "PLANNING FOR SECURITY".
Af: Bent Sørensen

111/85 "JORDEN RUNDT PÅ FLADE KORT".
Projektrapport af: Birgit Andresen, Beatriz Quinones og Jimmy Staal.
Vejleder: Mogens Niss.

112/85 "VIDENSKABELIGGØRELSE AF DANSK TEKNOLOGISK INNOVATION FREM TIL 1950 - BELYST VED EKSEMPLER".
Projektrapport af: Erik Odgaard Gade, Hans Hedal, Frank C. Ludvigsen, Annette Post Nielsen og Finn Physant.
Vejleder: Claus Bryld og Bent C. Jørgensen.

113/85 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS 11".
Af: Bernhelm Booss og Krzysztof Wojciechowski.

114/85 "ANVENDELSE AF GRAFISKE METODER TIL ANALYSE AF KONTIGENSTABELLER".
Projektrapport af: Lone Biilmann, Ole R. Jensen og Anne-Lise von Moos.
Vejleder: Jørgen Larsen.

115/85 "MATEMATIKKENS UDVIKLING OP TIL RENÆSSANCEN".
Af: Mogens Niss.

116/85 "A PHENOMENOLOGICAL MODEL FOR THE MEYER-NELDEL RULE".
Af: Jeppe C. Dyre.

117/85 "KRAFT & FJERNVARMEOPTIMERING"
Af: Jacob Mørch Pedersen.
Vejleder: Bent Sørensen

118/85 "TILFÆLDIGHEDEN OG NØDVENDIGHEDEN IFØLGE PEIRCE OG FYSIKKEN".
Af: Peder Voetmann Christiansen

119/86 "DET ER GANSKE VIST - - EUKLIDS FEMTE POSTULAT KUNNE NOK SKABE RØRE I ANDEDAMMEN".
Af: Iben Maj Christiansen
Vejleder: Mogens Niss.

120/86 "ET ANTAL STATISTISKE STANDARDMODELLER".
Af: Jørgen Larsen

121/86 "SIMULATION I KONTINUERT TID".
Af: Peder Voetmann Christiansen.

122/86 "ON THE MECHANISM OF GLASS IONIC CONDUCTIVITY".
Af: Jeppe C. Dyre.

123/86 "GYMNASIEFYSIKKEN OG DEN STORE VERDEN".
Fysiklærerforeningen, IMFUFA, RUC.

124/86 "OPGAVESAMLING I MATEMATIK".
Samtlige opgaver stillet i tiden 1974-jan. 1986.

125/86 "UVBY,β - systemet - en effektiv fotometrisk spektralklassifikation af B-,A- og F-stjerner".
Projektrapport af: Birger Lundgren.

126/86 "OM UDVIKLINGEN AF DEN SPECIELLE RELATIVITETSTEORI".
Projektrapport af: Lise Odgaard & Linda Szkotak Jensen
Vejledere: Karin Beyer & Stig Andur Pedersen.

127/86 "GALOIS' BIDRAG TIL UDVIKLINGEN AF DEN ABSTRAKTE ALGEBRA".
Projektrapport af: Pernille Sand, Heine Larsen & Lars Frandsen.
Vejleder: Mogens Niss.

128/86 "SMÅKRYB" - om ikke-standard analyse.
Projektrapport af: Niels Jørgensen & Mikael Klintorp.
Vejleder: Jeppe Dyre.

129/86 "PHYSICS IN SOCIETY"
Lecture Notes 1983 (1986)
Af: Bent Sørensen

130/86 "Studies in Wind Power"
Af: Bent Sørensen

131/86 "FYSIK OG SAMFUND" - Et integreret fysik/historieprojekt om naturanskuelsens historiske udvikling og dens samfundsmæssige betingethed.
Projektrapport af: Jakob Heckscher, Søren Brønd, Andy Wierød.
Vejledere: Jens Høyrup, Jørgen Vogelius, Jens Højgaard Jensen.

132/86 "FYSIK OG DANNELSE"
Projektrapport af: Søren Brønd, Andy Wierød.
Vejledere: Karin Beyer, Jørgen Vogelius.

133/86 "CHERNOBYL ACCIDENT: ASSESSING THE DATA.
ENERGY SERIES NO. 15.
AF: Bent Sørensen.

134/87 "THE D.C. AND THE A.C. ELECTRICAL TRANSPORT IN AsSeTe SYSTEM"
Authors: M.B.El-Den, N.B.Olsen, Ib Høst Pedersen, Petr Viščor

135/87 "INTUITIONISTISK MATEMATIKS METODER OG ERKENDELSESTEORETISKE FORUDSÆTNINGER"
MASTEMATIKSPECIALE: Claus Larsen
Vejledere: Anton Jensen og Stig Andur Pedersen

136/87 "Mystisk og naturlig filosofi: En skitse af kristendommens første og andet møde med græsk filosofi"
Projektrapport af Frank Colding Ludvigsen
Vejledere: Historie: Ib Thiersen
Fysik: Jens Højgaard Jensen

137/87 "HOPMODELLER FOR ELEKTRISK LEDNING I UORDNEDE FASTE STOFFER" - Resume af licentiatafhandling
Af: Jeppe Dyre
Vejledere: Niels Boye Olsen og Peder Voetmann Christiansen.

138/87 "JOSEPHSON EFFECT AND CIRCLE MAP."

Paper presented at The International Workshop on Teaching Nonlinear Phenomena at Universities and Schools, "Chaos in Education". Balaton, Hungary, 26 April-2 May 1987.

By: Peder Voetmann Christiansen

139/87 "Machbarkeit nichtbeherrschbarer Technik durch Fortschritte in der Erkennbarkeit der Natur"

Af: Bernhelm Booss-Bavnbek
Martin Bohle-Carbonell

140/87 "ON THE TOPOLOGY OF SPACES OF HOLOMORPHIC MAPS"

By: Jens Gravesen

141/87 "RADIOMETERS UDVIKLING AF BLODGASAPPARATUR - ET TEKNOLOGIHISTORISK PROJEKT"

Projektrapport af Finn C. Physant

Vejleder: Ib Thiersen

142/87 "The Calderón Projektor for Operators With Splitting Elliptic Symbols"

by: Bernhelm Booss-Bavnbek og
Krzysztof P. Wojciechowski

143/87 "Kursusmateriale til Matematik på NAT-BAS"

af: Mogens Brun Heefelt

144/87 "Context and Non-Locality - A Peircan Approach

Paper presented at the Symposium on the Foundations of Modern Physics The Copenhagen Interpretation 60 Years after the Como Lecture. Joensuu, Finland, 6 - 8 august 1987.

By: Peder Voetmann Christiansen

145/87 "AIMS AND SCOPE OF APPLICATIONS AND MODELLING IN MATHEMATICS CURRICULA"

Manuscript of a plenary lecture delivered at ICMTA 3, Kassel, FRG 8.-11.9.1987

By: Mogens Niss

146/87 "BESTEMMELSE AF BULKRESISTIVITETEN I SILICIUM"

- en ny frekvensbaseret målemetode.

Fysikspeciale af Jan Vedde

Vejledere: Niels Boye Olsen & Petr Viščor

147/87 "Rapport om BIS på NAT-BAS"

redigeret af: Mogens Brun Heefelt

148/87 "Naturvidenskabsundervisning med Samfundsperspektiv"

af: Peter Colding-Jørgensen DLH
Albert Chr. Paulsen

149/87 "In-Situ Measurements of the density of amorphous germanium prepared in ultra high vacuum"

by: Petr Viščor

150/87 "Structure and the Existence of the first sharp diffraction peak in amorphous germanium prepared in UHV and measured in-situ"

by: Petr Viščor

151/87 "DYNAMISK PROGRAMMERING"

Matematikprojekt af:
Birgit Andresen, Keld Nielsen og Jimmy Staal

Vejleder: Mogens Niss

152/87 "PSEUDO-DIFFERENTIAL PROJECTIONS AND THE TOPOLOGY OF CERTAIN SPACES OF ELLIPTIC BOUNDARY VALUE PROBLEMS"

by: Bernhelm Booss-Bavnbek
Krzysztof P. Wojciechowski

153/88 "HALVLEDERTEKNOLOGIENS UDVIKLING MELLEM MILITÆRE OG CIVILE KRÆFTER"

Et eksempel på humanistisk teknologihistorie
Historiespeciale

Af: Hans Hedal

Vejleder: Ib Thiersen

154/88 "MASTER EQUATION APPROACH TO VISCOUS LIQUIDS AND THE GLASS TRANSITION"

By: Jeppe Dyre

155/88 "A NOTE ON THE ACTION OF THE POISSON SOLUTION OPERATOR TO THE DIRICHLET PROBLEM FOR A FORMALLY SELFADJOINT DIFFERENTIAL OPERATOR"

by: Michael Pedersen

156/88 "THE RANDOM FREE ENERGY BARRIER MODEL FOR AC CONDUCTION IN DISORDERED SOLIDS"

by: Jeppe C. Dyre

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